Influences of High content of sodium doping at Cu site of Bi(Pb)2212

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Research Article

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Abstract

We study here, the effect of high content of sodium doping on structural and electrical properties of Bi(Pb)2212 superconducting. The X-ray analysis results showed that all the prepared samples mainly belong to the superconducting tetragonal phase Bi-(Pb)2212. SEM micrographs show that the grains are closely related and have a characteristic flat shape for the superconductor Bi (Pb) 2212. For the undoped sample, the grains are randomly distributed with a size of 5 μm. For doped samples, the morphology changes with sodium concentration. Resistivity measurements show that all samples have a superconducting character.

1 Introduction

The bismuth cuprate substitutions mainly concerned the Bi2223 phase and the Bi site for stability of the phase. The replacement of bismuth by lead [1] or antimony allows synthesizing compounds with stable superconducting properties and a higher Tc. This is the consequence of partial change induced by the substitution of the bismuth atom by another with lower valence [2]. A stoichiometric proportion of 15% of Pb, in place of Bi, is sufficient to obtain a pure and stable Bi2223 phase, as shown by Ertan Sahin *et al* [3]. As Regards the Bi2212 phase, the replacement of Bi by Pb considerably improved the superconducting properties. If the oxygen stoichiometry has been well controlled, an improvement in critical current density can be achieved up to 77 K [4–6]. in the Bi2212 phase, a partial substitution of the divalent elements such as Ca^{+2} or Sr^{+2} by trivalent rare earths (RE), changed the concentration of the holes in the CuO_2 planes [7–9]. This leads to an optimal concentration of carriers, which in turn improves the critical temperature (Tc) of the system [10]. Substitution on Cu sites is fundamentally different from the one made on Ca sites. The effect of the first one is stronger because it affects the superconducting properties by changes in the CuO_2 planes when the second one affects primarily the charge reservoir. Many studies have dealt with the influence of doping in the copper site such as with Ni or Zn. In addition, a decrease of Tc upon substitution by both nickel and zinc was observed [11]. The decrease induced by cobalt is much higher than that induced by zinc except that for this last one thesuperconductivity disappears.

2 Experimental

2.1 Synthesis

A series of samples of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_{2-x}Na_xO_{8+\delta}$, where x = 0-0.4,were prepared by the solid state reaction with a stoichiometric ratio. After that, it was calcined in two steps: the first at 800 ° C for 10h and the second at 810 ° C for 30h with intermediate grinding. Then, pressed into the form of pellets under a pressure of 225 MPa, and sintered twice at 840 ° C for 50 h and the heating rate was 5 ° C / min.

1.2. Characterization

All samples were characterized by X-ray diffraction pattern (XRD) was recorded using a Bruker D8 Advance diffractometer, using CuKa radiation from copper (λCuKa = 1.5418Å) and STEP 0.02. The measurement was performed in the 2θ range of 10°–80° and for the identification of the existing phases we have used the JCPD-ICDD data file [12]. The lattice parameters of the Bi (Pb) 2212 and Bi (Pb, Na) 2212 phases were identified using the DicVol software [13]. Photomicrographs were taken under a scanning electron microscope. The electrical resistivity was measured by a conventional four-probe technique.

3 Results And Discussion

3.1 Structural and morphological properties

The XRD spectra of samples containing a proportion of sodium x = 0, 0.2 and 0.4 are represented in Fig. 1. These spectra show the obtaining of the phase Bi(Pb, Na)2212 phase together with Ca_2PbO_4 and traces of Bi2201 parasitic phases. Texturing along (00*l*) can be observed. When sodium is introduced into the Cu site, we notice a significant decrease in the intensity of the main peaks of the parasitic phase Ca_2PbO_4 and (0 0 8), (0 0 10) and (0 0 12) of Bi (Pb, Na) 2212 phase, and we also notice a shift in the angular position of the peaks to the left by 2θ = 0.12 degrees. The intensity of the peaks having an angular position 2θ between 40° and 60° decreases to become background noise. For the samples containing sodium, the peaks are shifted to the left of those belonging to the undoped (Bi, Pb)2212 phase (x = 0). Displacement is very low, of the order of 2θ = 0.06° for x = 0.2. For the other rates, 0.4, the displacement is twice, of the order of 2θ = 0.12°. These displacements suggest a saturation effect in the substitution by sodium and a limit of solubility of sodium in the (Bi, Pb)2212 phase at a rate less or equal to 0.4. The table 1 summarized the lattice parameters a, c, and volume of the unit cell of the crystal lattice of the samples doped with sodium. Figure 2 shows the variations of the lattice parameters a, and c versus the rate x of sodium. The parameter c goes through a maximum and the parameter a through a minimum. The introduction of sodium results in a reduction of the lattice parameters compared to the phase without sodium except c for x = 0.4, which the values are greater. The variations of the volume of the unit cell are very low, except for x = 0.4 where a significant contraction is observed. The sodium has an ionic radius of 0.99 Å greater than that of copper (0.57 Å considering a fourfold coordination number) [14] but a lower valence + 1. On the other hand with a configuration $2s^2 2p^6$, the Na^+ ion has no spin. The substitution of sodium copper on the Cu site will therefore lead to a reduction of holes at the CuO_2 planes.

Figure 3 presents the SEM images of the three samples. The undoped sample (Fig. 3.a) shows a layered structure characterizing the grain growth of Bi (Pb) 2212 phase. Small white nodules may be noticed due to some sediment in the starting powder. The particles seem quite dense and well connected. Figures 3b and 3c show the microstructure of the compounds Bi(Pb)2212 doped with sodium. The grain shape is flattened and a lamellar structure can be noticed in many of them. The grains are fairly dense and well connected. Grains seem to have the same alignment. The sample with x = 0.2 has a lamellar structure observed above. Grains have the same shape and flattened orientation seems more random. Morphology has also changed. Size has a distribution closer to average with many grains of about 1μm. With x = 0.4 the porosity increases compared to the one of sample with x = 0.2. The grain morphology is comparable to that observed in the previous sample. Size has a distribution closer to average with many grains of about 1μm.

Table 1. The lattice parameters ***a, c*** and volume of the unit cell of the samples.

Rate x *of Na*	*a* (Å)	*c* (Å)	*V* (Å)
0	5.398	30.845	898.86
0.2	5.395	30.827	897.35
0.4	5.084	30.909	799.03

1.2. Electrical properties

The variation of resistivity as a function of temperature is illustrated in Fig. 4. This variation presents a pseudo-metallic behavior before the transition (normal state region). The resistivity in the normal state of the undoped sample (x = 0) is much higher than those of the other samples. The sample with x = 0.4 has the lowest resistivity at room temperature. The part of the curve corresponding to the normal state shows the charge carrier density as a function of x. This density is inversely proportional to the residual resistivity ρ_0, which is extrapolated from the normal part of ρ(T) at 0 K to 235 K and reported in Table 2, ρ_0 has the lowest value at x = 0.4. The corresponding samples also have the smallest width of transition ΔT, which is reported in Table 2 and represents the difference between Tconset and Tczero. Introduction of sodium caused Tconset to drop from 68.58 K at x = 0.2 until 56.01 K at x = 0.4. In contrast, for the un-doped sample at 50.65 K, Tczero increases to x = 0.2 at 55.5 K and then decreases to 45.59 K at x = 0.4. The fall of Tconset is expected because Na is substituted on the Cu site and introduces interferences in the CuO_2 plane. However, lower values of ρ_0 and ΔT for x = 0.2 suggest that improvements can be obtained at low doping levels.

Table 2. Residual resistivity ρ_0, Tc^{onset}, Tc_{off} and ΔT of the samples.

Rate x of Na	$\rho_0(\Omega cm)$	Tc^{onset} *(K)*	Tc_{zero}*(K)*	*ΔT(K)*
0	0.0072	81.57	50.65	30.92
0.2	0.0035	68.58	55.59	12.99
0.4	0.0031	50.04	45.59	4.45

5 Conclusions

Doping $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_{8+\delta}$ by sodium was performed by substitution at copper site with concentrations x = 0.2, 0.4. The phase Bi(Pb, Na)2212 is obtained with a major fraction, accompanied by parasitic phases Bi(Pb)2201 and Ca_2PbO_4. Lower cell parameter ***a***, and ***c*** is observed except for sodium with x = 0.4, where ***c*** increases. Doping with sodium at the level of the Bi (Pb) 2212 phase reduces the Tconset. Moreover, an increase in the level of sodium not only reduces the quality of the grains but also the grain boundaries.

Declarations

Conflict of interests

The authors declare that they have no conflict of interests.

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Author contributions

Data collection and analysis were performed by [Faiza Bouaïcha]. The first draft of the manuscript was written by [Faiza Bouaïcha] and prepared all figures and corrected the main manuscript.

[Mohamed Fayçal Mosbah]: corrected the main manuscript text.

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All authors reviewed the manuscript.

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Figures

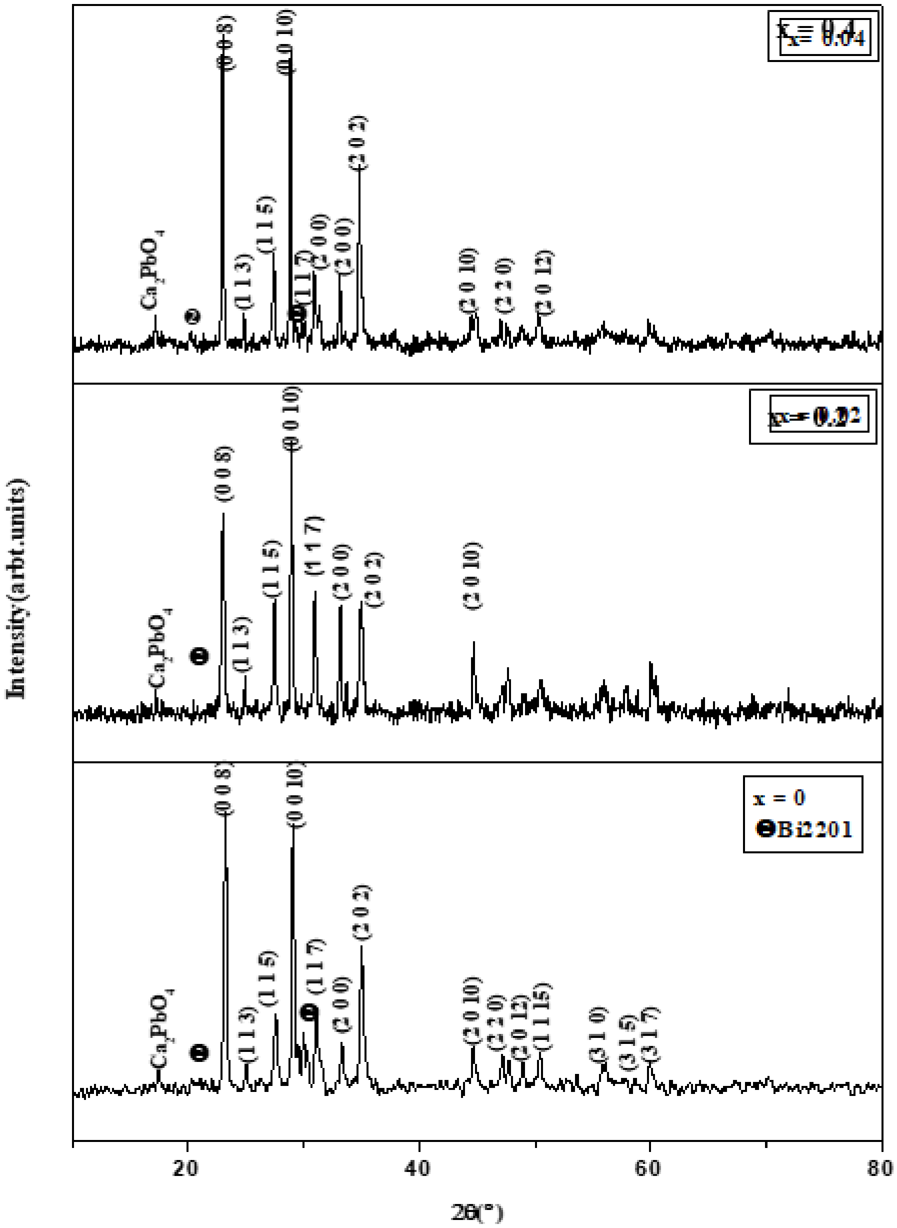

Figure 1

X-ray diffraction patterns of the Bi2212 samples doped with Pb and Na.

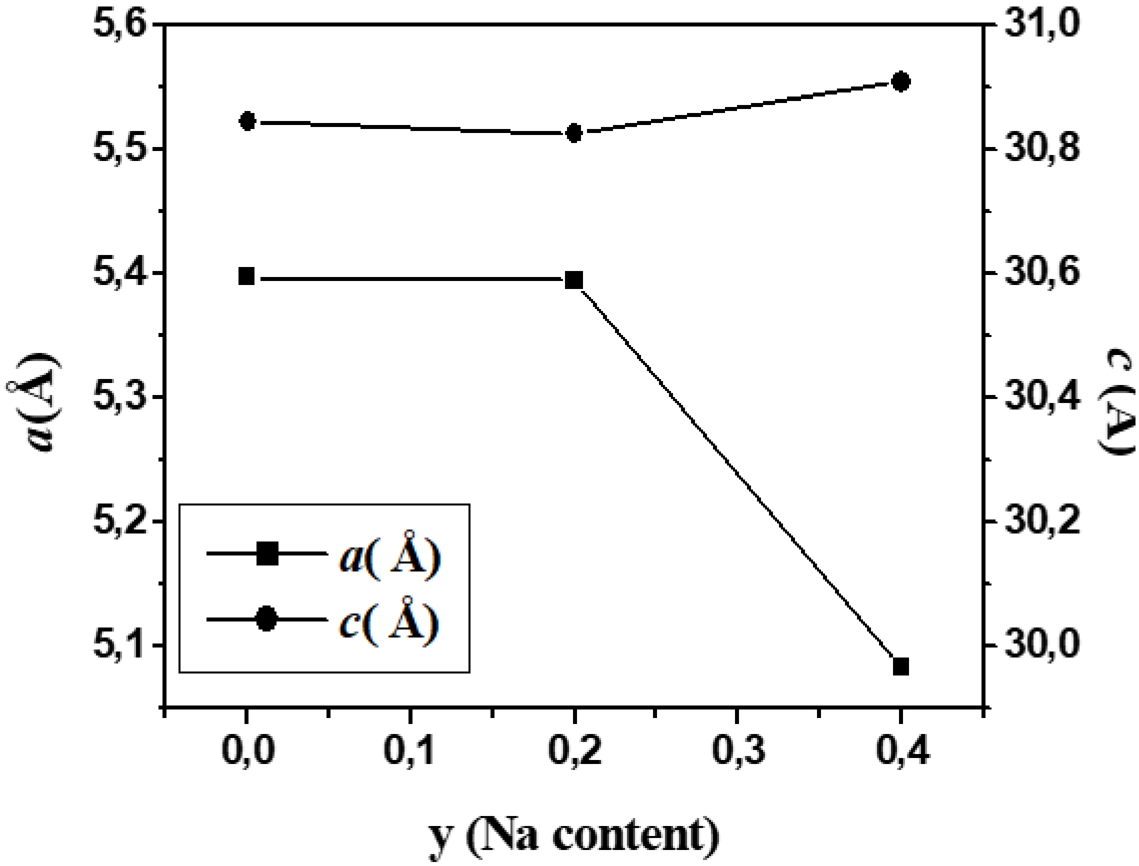

Figure 2

Variation of ***a*** and ***c***-axis cell parameter versus the rate ***x*** of Na

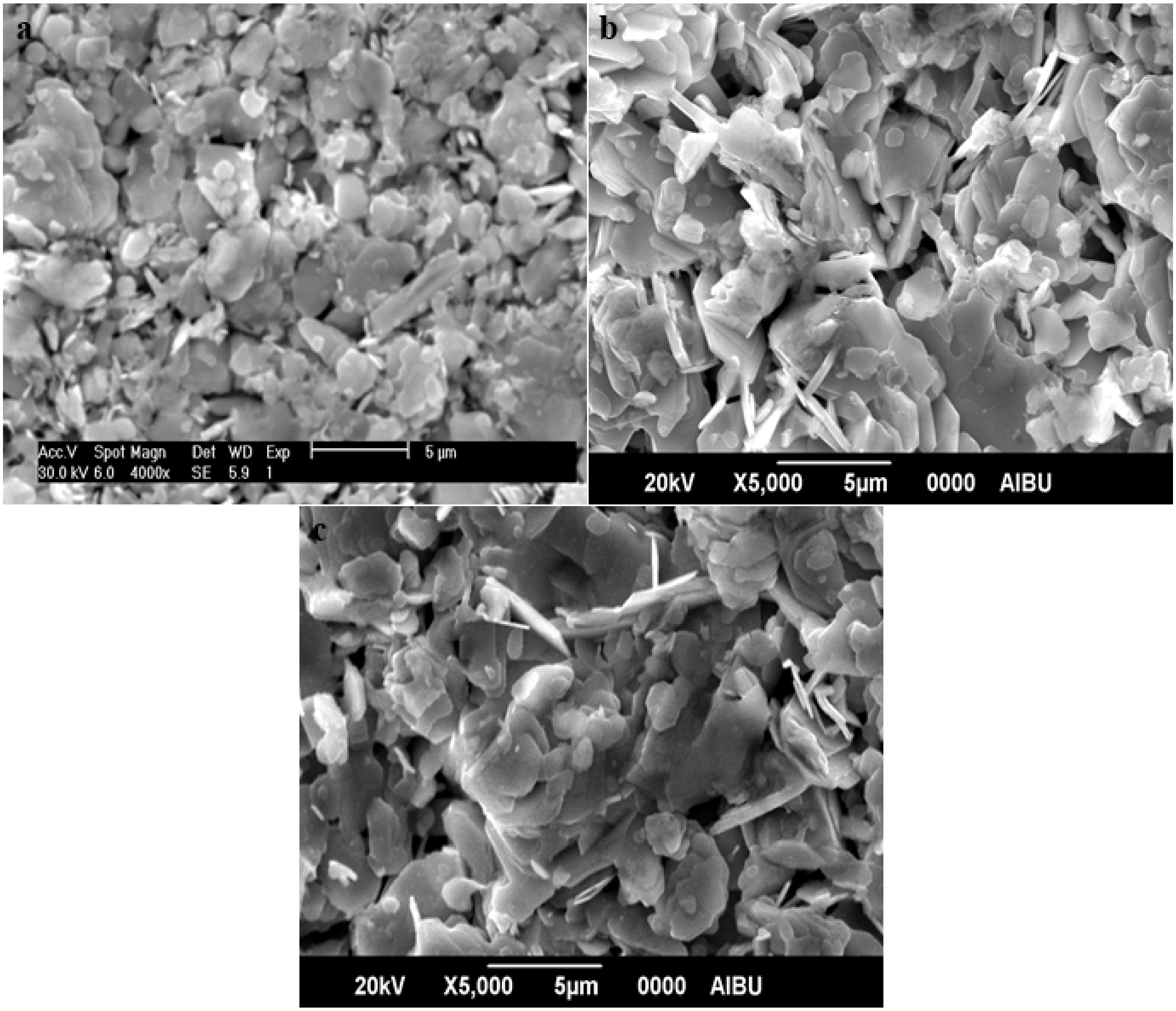

Figure 3

SEM Micrographs of an undoped (a); (b) doped (x = 0.2), and (c) doped (x = 0.4) samples

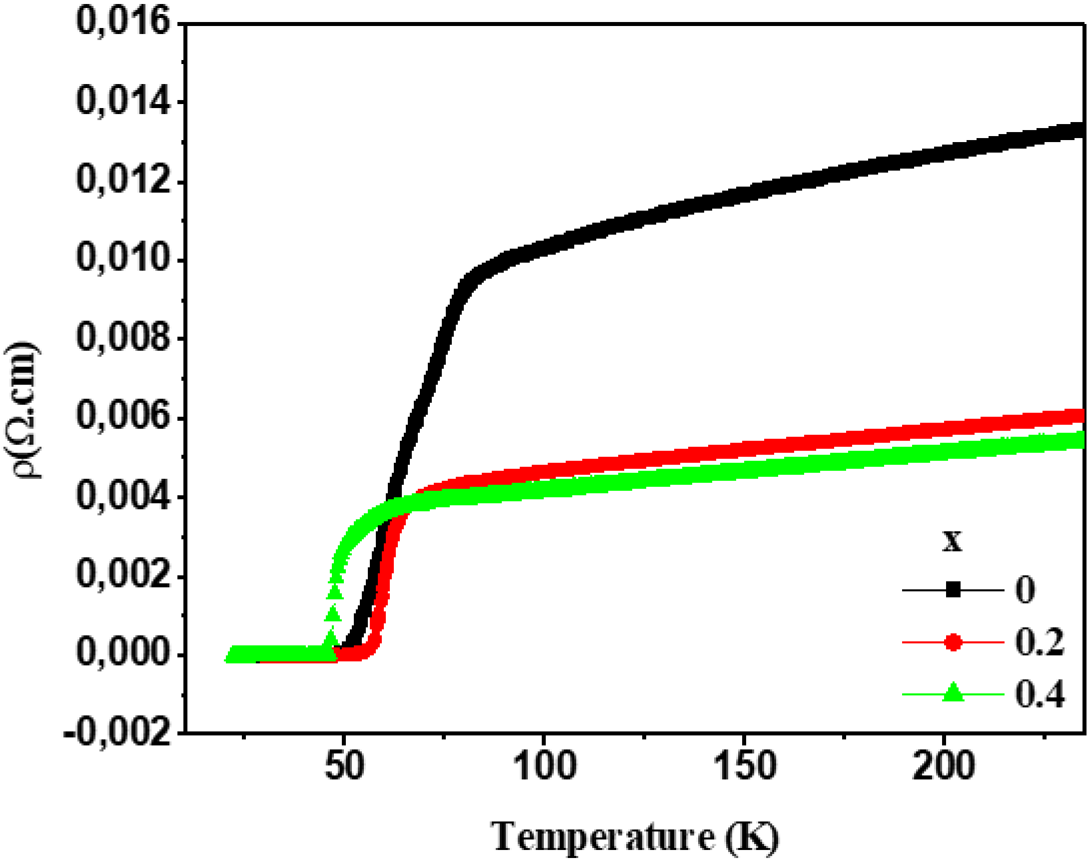

Fig 4. Resistivity versus time measurements ρ(T) of the samples where: ■ undoped; ● x = 0.2; ▲ x =0.4

Figure 4

See image above for figure legend